Study on Performance of Paver Block using Prosopis Juliflora Ash

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GRAPHICAL ABSTRACT

Abstract

The use of Prosopis Juliflora (PJ) ash as a supplementary replacement for cement in paver block production presents a promising sustainable solution for the construction industry. PJ is an invasive plant species that poses significant environmental and socio-economic challenges in many regions. This research paper explores the feasibility and potential benefits of incorporating PJ ash as a supplementary cementitious material in paver blocks. The study investigates the mechanical, durability, and environmental aspects of the paver blocks with differing levels of PJ ash content. The results demonstrate that the incorporation of PJ ash in paver blocks not only diminish the environmental impact but also escalate their mechanical and durability properties. This research contributes to sustainable construction practices by promoting the utilization of waste materials and addressing the issues associated with invasive plant species. By weight of cement, PJ ash is utilised in quantities of 0%, 5%, 10%, 15%, 20%, 25%, 30%. In this study, Prosopis Juliflora Ash (PJA), which has a specific gravity of 3.00 and a mean particle size of 35 micron, was utilised to partially replace cement. As a result, it can be concluded that the inclusion of PJ ash up to a certain replacement level (15%) can enhance the mechanical properties of the paver blocks. However, beyond this replacement level, a slight reduction in strength was observed. These findings provide valuable insights into the mechanical properties of paver blocks incorporating PJ ash and emphasize its potential as a sustainable alternative in the construction industry.

Keywords: prosopis juliflora, paver block, mechanical properties, waste materials

1. Introduction

Construction industry is a significant contributor to environmental degradation and resource depletion. Cement is the most widely used construction materials, is responsible for a considerable amount of carbon dioxide (CO_2) emissions due to the energy-intensive process of its production. Additionally, the increasing demand for cement has led to the depletion of natural resources, such as limestone and clay. Therefore, the search for sustainable alternatives that can diminish the environmental hazards of cement usage is crucial[1]. One such alternative lies in the utilization of waste materials as Supplementary-Cementitious Materials (SCMs) in construction applications. SCMs not only contribute to the conservation of natural resources but also help in reducing CO_2 emissions. Prosopis Juliflora Ash (PJA) a waste material derived from the combustion of Prosopis juliflora, an invasive plant species found in various parts of the world, has recently gained attention as a potential SCM in construction materials.Prosopis juliflora, commonly known as mesquite, is an aggressive invasive plant that poses severe ecological and socio-economic challenges. It colonizes vast areas, depleting water resources and displacing native flora and fauna. Control and eradication measures for PJ have proven to be costly and challenging. Thus, finding sustainable and environmentally friendly solutions for managing this invasive plant species is of utmost importance[2],[3],[4]. Paver blocks are often utilised in two region, namely queue and non-traffic areas, in accordance with the field standards. While pedestrian, parking, and garden areas are considered non-traffic regions, mild to very strong traffic is considered in traffic areas. The compressive strength of the paver blocks, which ranges from M 30 to M 55, is used to determine the grade designation. M35 to M55 grades are for vehicular usage; M30 grades are for pedestrians. According to IS: 15658 - 2006, other parameters, such as tensile strength, flexural strength, freeze-thaw behaviour, and colour and texture, are optional. The mandatory requirements include water absorption, compressive strength, and abrasion level. Worldwide, paver blocks are produced in accordance with the necessary specifications. whereas and IS 15658 specify the minimum compression strength and tensile splitting strength[5].

Several studies have investigated the feasibility of utilizing PJ ash in various construction materials, including concrete and mortar. However, limited research has focused on its application in paver blocks, which are extensively used in pavements, walkways, and driveways. Paver blocks offer excellent durability, strength, and aesthetics, making them a popular choice for outdoor applications. Therefore, exploring the potential of PJ ash as a supplementary replacement for cement in paver blocks is an interesting avenue worth investigating. One of the key factors in evaluating the performance of paver blocks is their compressive strength, which determines their ability to withstand applied loads. In this work the compressive strength of paver blocks incorporating Prosopis juliflora (PJ) ash as a partial-replacement for cement was investigated. The aim was to assess the effect of varying levels of PJ ash content on the crushing strength of the paver blocks and compare it with conventional paver blocks without PJ ash[6],[7].

Researcher examined the impact of PJ ash on the mechanical behaviour and microstructure of mortar. The workability of the mixes was observed in such a way that cement and PJA mixtures including 10 and 20% require an ideal water range of 35% to maintain adequate consistency, but mixes containing 30 and 50% PJA resulted in a consistency value of 38%. This study revealed that the addition of PJ ash as a cement replacement improved the compressive strength and reduced the porosity of the mortar[8]. The researchers attributed these improvements to the pozzolanic activity of PJ ash, which enhanced the formation of calcium silicate hydrate (C-S-H) gel, responsible for the strength and durability of cementitious materials [9],[10]. This study investigated the compressive strength of paver blocks with varying amounts of fly ash (0% to 25%), and results revealed that when 20% of the fly ash was substituted with OPC 33 grade cement, the mixture had higher strength than usual. Although it appears that the Compressive Strength continues to improve as Fly Ash levels rise, after a 20% replacement, the strength appears to be diminishing. Finally, it can be inferred that the crushing strength of paver blocks after 28 days of 20% Fly Ash partial cement substitution is high. The highest compressive strength of paver blocks for OPC 33 grade with 20% fly ash is 28, 36, and 42 MPa at 7, 21, and 28 days. While the use of PJ ash as an SCM in concrete and mortar has been explored, its application in paver blocks remains relatively unexplored. However, further research is needed to explore the specific characteristics and performance of paver blocks incorporating PJ ash. Five mixes were created, each comprising waste glass in quantities of 15, 20, 25, 30 and 40% as a partial substitute for fine aggregates, in contrast to a control mix that only contained natural aggregate[11].

Because the broken glass had a lower fineness modulus of fineness than the natural aggregate, small changes were required to each mix design to maintain the desired levels of strength and workability. With a water to binders ratio of 0.45, three different range of concrete mix were created, including the control mix mixture (Natural Aggregate substitution of 5%, 10%, 15%, and 20% by weight of cement). The findings from such studies will contribute to the growing body of knowledge on waste material utilization and provide insights into sustainable construction practices. The paver blocks were produced using a mix design that included cement, sand, coarse aggregates, and varying percentages of PJ ash as a replacement for cement. The specimens were cast in accordance with the relevant standards and cured under controlled conditions. After the specified curing period, the paver blocks were subjected to compressive strength testing using a compression testing machine. The results obtained from the compressive strength tests were analyzed and compared to find the effect of PJ ash content on the strength properties of the paver blocks. Paver blocks are widely used in pavements, walkways, and driveways due to their durability and aesthetic appeal[12]. Incorporating PJ ash in paver block production could offer additional benefits in terms of strength, durability, and environmental sustainability. In conclusion, the utilization of PJ ash as a partial replacement for cement in paver blocks presents a promising avenue for sustainable construction. Previous studies have demonstrated the positive effects of PJ ash on the mechanical and durability of concrete and mortar.

The originality of the study includes an experimental investigation made for the mechanical and durability properties of paver block using Prosopis Juliflora Ash (PJA) as a partial replacement of cement from 0% to 30% by weight of cement.

2. Materials and Methods

2.1 Cement

Ordinary Portland Cement of 53 grade confirming to IS: 12269-2013 was taken from Virudhunagar and tested for its consistency, fineness and soundness test as per IS 4031:1988. Similarly, the specific gravity of the cement was determined in accordance with IS 2720-1980. It has a specific gravity of 3.10 and soundness of 4.5mm. Table 1 provide the properties of cement.

Table 1 Physical Properties of Cement

Test	Result
Specific gravity	3.10
Standard Consistency	31 %
Initial Setting Time of Cement	75 minutes
Final Setting Time of cement	390 minutes

Soundness	4.5mm

2.2 Prosopis Juliflora Ash (PJA)

Prosopis Juliflora Ash was obtained from Madurai. It has been prepared from the uncontrolled burning of wood (Prosopis Juliflora) and heated in furnace at 550^{0}C for 240 minutes. The PJA has been sieved in IS 90 µm sieve. To increase the durability of concrete paver blocks, PJA has been added. Prosopis Juliflora Ash (PJA), which has a specific gravity of 3.00 and a mean particle of 35 micron, was utilised to partially replace cement.

Table 2 Physical Properties of Prosopis Juliflora Ash

Test	**Result**
Specific gravity	3.14
Standard Consistency	29 %
Initial Setting Time of PJA	70 minutes
Final Setting Time of PJA	400 minutes
Soundness	5.3mm

3. Experimental work

Cement is a material that can bind various substances together and hardens and sets after setting. In general, cement can be described as a substance with excellent adhesive and constructive qualities that enable bonding with different materials to produce compact masses. The paver block is cast using cement of OPC grade 33. According to IS specifications, the cement's compressive strength after a 28-day test is 33 MPa. A granular substance, such as sand, gravel, crushed stone, or aggregate that was retained after passing through a 4.75 mm IS sieve. The role of the fine aggregate is to function as a workability agent and to fill the gaps left by the coarse aggregate. When making the paver blocks, PJ ash is utilised as an ingredient.

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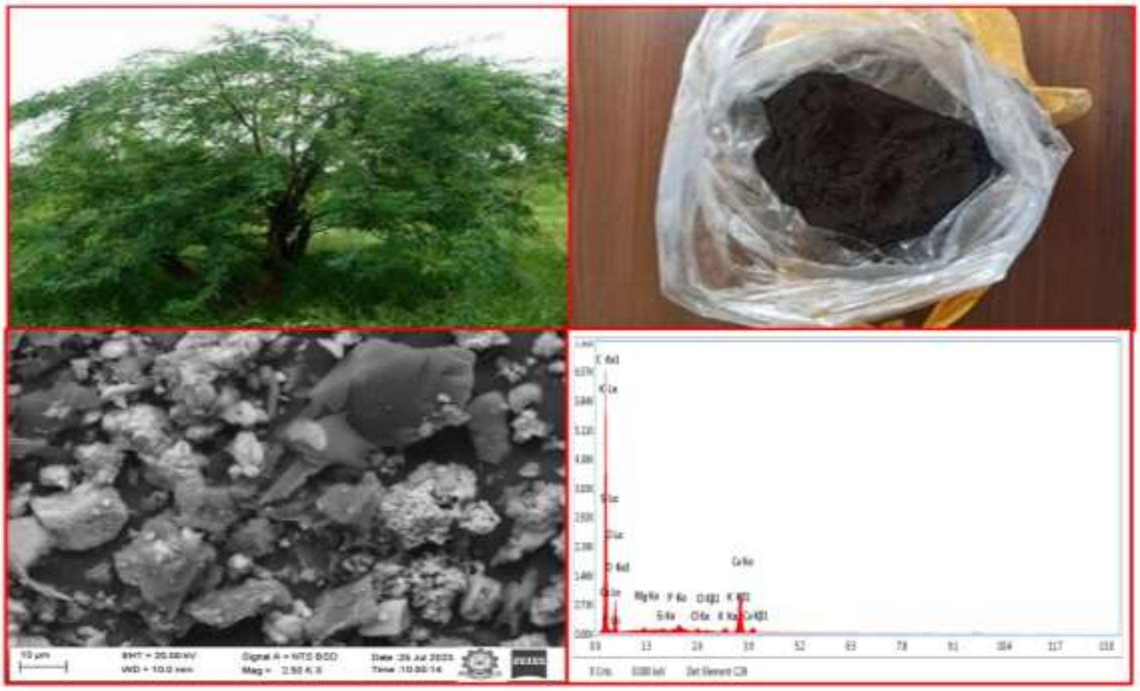

Figure 1: Prosopis Juliflora Ash and SEM Analysis

Table 3: Chemical Properties of PJA

Element	%
Ca	76.9
Mg	0.5
Si	0.2
O	17.8
K	0.3

Figure 1 shows SEM image of PJA and it indicates clearly a micro porous surface with honeycomb shaped pores. The elemental analysis of ash was done by using EDX analysis and is shown in Figure 1. By weight of cement, PJ ash is utilised in quantities of 0%, 5%, 10%, 15%, 20%, 25%, 30% it is indicated in Table 4. In this study, Prosopis Juliflora Ash (PJA), which has a specific gravity of 3.00 and a mean particle of 35 micron, was utilised to partially replace cement. The mixes were created in accordance with IS 10262:2009, an Indian standard [13]. The mixtures were compacted in three layers before being put into the cube moulds. For the specified testing duration, the moulds were dried in a water bath at room temperature. To increase the durability of concrete paver blocks, PJA has been added. The concrete mix of M35 grade (Cement(binder) : Fine aggregate: Coarse Aggregate :Water= 1 : 1.598 : 2.85:0.45) was adopted as it is the grade for mild traffic. This study's concrete mix designs were implemented in accordance with the procedures outlined in IS (Indian Standards). After 28 days, all mixes were proportioned to have a design compressive strength of 30 MPa[14],[15].

Table -4 Symbol Description

DESCRIPTIONS	SYMBOLS
Control Mix	PB 0%
5% of PJA by using weight of cement	PB 5%
10% of PJA by using weight of cement	PB 10%
15% of PJA by using weight of cement	PB 15%
20% of PJA by using weight of cement	PB 20%

25% of PJA by using weight of cement	PB 25%
30% of PJA by using weight of cement	PB 30%

Figure 2: Overview of the project

Table 5: Mechanical study of PJ ash paver block

Properties	Days	PB 0% N/mm²	PB 5% N/mm²	PB 10% N/mm²	PB 15% N/mm²	PB 20% N/mm²	PB 25% N/mm²	PB 30% N/mm²
Compressive strength	14	18.09	14.46	16.22	18.56	16.39	14.22	13.03
	28	29.1	32.21	36.87	38.98	27.36	25.89	24.32
Flexural strength	14	0.35	0.36	0.44	0.44	0.39	0.35	0.32
	28	0.54	0.56	0.6	0.63	0.45	0.43	0.39
Water Absorption	7	4.23	3.65	3.55	3.28	4.88	5.22	5.67
Rebound Hammer Test	28	28.77	31.22	35.76	37.66	26.45	24.21	23.88

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4. Results and Discussion

4.1 Compressive Strength

On compression testing equipment with a 200 Ton capacity, the casted PJ ash paver block is placed for testing the compressive strength is shown in Figure 2. Before the operation began, the machine's bearing surface grimed and other impurities had been thoroughly cleaned off. A continuous load is applied until the specimen can bear and above that it can no longer sustain itself and eventually fell apart. The applied pressure had been continuously observed. On the specimens, the highest load that was applied was noted. The 7th and 28th day crushing strength test is taken for the specimen is shown in Table 5. Both the control mix and the PJ ash mix do not vary much. PB 15% has higher compressive strength than all other mix proportion. According to the findings of the investigations, the fine structure of Prosopis Juliflora ash fills more voids and provides superior pore structure, improving its strength at later stages due to lower permeability up to 30% replacement. When making paver blocks, prosopis juliflora ash can efficiently substitute up to 15% of the cement gives higher compressive strength due to the fine particles of Prosopis Juliflora Ash and because of filling the voids. However, when the amount of PJA is increased, ettringite formation is delayed due to a higher SO_3 content, which may also impede alite formation. Furthermore, according to the literature research, compressive strength was lowered after 30% replacement due to a decrease in the development of C-S-H gels and an increase in the intensity of Plazolite [12].

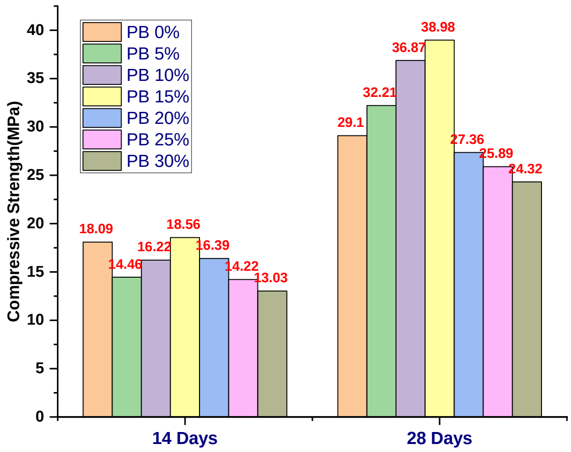

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Figure 3 : Compressive strength of PJ ash

4.2 Flexural Strength

As IS 516, with the following: The diameter of the loading and securing rollers must fall between 25 and 40 mm. The two supporting rollers' center-to-centre distance must be adjustable to the overall length of the specimen minus 50 mm. The loading roller must be set up to apply load from the top of the specimen along the vertical center line between the supporting rollers. They must extend on both sides by at least 10 mm beyond the dimensions of the specimens. Flexural strength of paver block was calculated using this formula is shown in Figure 4. PB 15% has higher Flexural strength than all other mix proportion. Both the control mix and the PJ ash mix do not vary much. As a result, it can be concluded that PJA addition has no impact on bending strength at any age.

The flexural strength of the specimen shall be calculated as follows:

$$F = 3PL/2BD^2$$

Where;

F = flexural strength, in N/mm^2
P = Maximum load, in N
L = distance between central lines of rollers, in mm
B = width of block, in mm
D = average thickness in mm

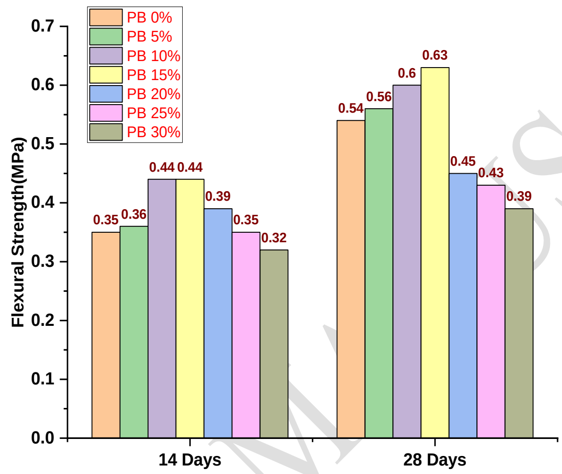

Figure 4: Flexural strength of PJ ash

The specimen of PB15% has been performed well in the flexural point of view when compared to the control specimen. From the observation, for higher percentage of replacement the flexural strength has been reduced due to the cracking formation in the tension zone of the prism.

4.3 Water Absorption

According to ASTM C140-11a , a water absorption test was conducted. The specimens were submerged in water for 24 to 28 hours at a temperature of 15 to 26°C so that the upper surfaces of the specimens are at least 6 inches (152 mm) below the water's surface. At least 18 inches of space must be kept between each specimen. The samples are weighed as they are suspended from completely saturated in water, and the immersed weight (Wi) is noted and water absorption range is shown in Figure 5

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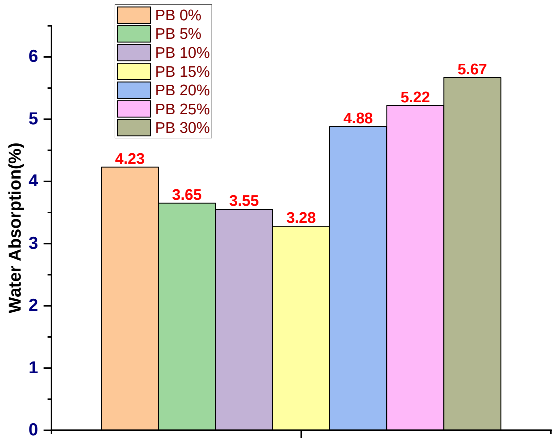

Figure 5: Water absorption of PJ ash

. The wire mesh of 3/8 inch (9.5mm) was placed in, any apparent water was removed with a cloth, and left to drain for 60 ± 5 seconds before being weighed and mentioned as Ws (saturated weight). The desiccated specimens' weight was recorded as Wd after being dried in a oven at 100 to 115°C for at least 24 hours (oven-dry weight). Both the control mix and the PJ ash mix do not vary much. PB25% having lower water absorption value than PB 5%,PB10%,PB15%,PB20%,PB30%.

$$\text{Proportion of water absorbed} = \frac{Ws - Wd}{Wd} * 100\%$$

where,

W_d - Weight of specimen after oven-drying (kg);

Ws - Sample's saturated weight (kg)

Water absorption results for the specimen PB15%, PB20%, PB 25% have been gradually increased as 3.28%, 4. 88% and 5.22% respectively due to the reaction of water and Prosopis Juliflora Ash. PB30% has maximum water absorption of 5.67% due to higher content of PJA.

Conclusion

- The cementitious properties of PJ ash, which are responsible for strength formation, are present on their own. The material study on PJ ash highlights its potential as a supplementary replacement for cement in paver block production. The characterization tests confirmed the pozzolanic nature, fine particle size distribution, and suitable chemical composition of PJ ash. These properties indicate its ability to contribute to the strength development and durability of paver blocks.

- The incorporation of PJ ash as a sustainable alternative not only reduces waste and promotes resource conservation but also offers an environmentally friendly solution for the construction industry[16] and [17]. Further research is warranted to optimize the PJ ash content and explore its influence on the durability behaviour of paver blocks to fully understand its performance characteristics. The pozzolanic activity of PJ ash was evaluated through to react with calcium hydroxide, a byproduct of cement hydration, and form additional calcium silicate hydrate (C-S-H) gel formation.

- The results demonstrated the pozzolanic nature of PJ ash, indicating its potential to contribute to the strength and durability of paver blocks.However, when there is water present, it combines with the free lime in the cement to create hydrated products (C2S-Dicalcium Silicate and C3S-Tricalcium Silicate), which aid in achieving strength and

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enhance durability.

- Because of its extremely fine structure, PJ ash fills more gaps and offers superior pore structure, which enhances strength later because of decreased permeability. When BBC is used in place of cement to a greater extent than 1%, the crushing strength decreases as the reduction in cement content leads to reduction in CSH gel formation. PJ ash were replaced with cement of 0 to 30% in M 35.

- Increase in PJ ash addition leads to increase in compressive strength has a higher composition of Aluminium and Silica.Water absorption for PJ ash paver block for all the mix ratios of is within the limit. It proved that the waste burned wood are used as ash in cement can be make eco-friendly paver block.Hence, ash with 15% substitution of cement in paver block can be used as a replacement of conventional paver blocks.

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